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TEACHING NOTE

COST ESTIMATING METHODOLOGIES
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INTRODUCTION

A cost estimate is an evaluation/analysis of future costs of hardware or services generally derived by relating historical cost, performance, schedule and technical data of similar items or services.

Chapter 2, DoD 5000.4-M identifies four major analytical methods or cost estimating techniques used to develop cost estimates for acquisition programs: Analogy, Parametric (Statistical), Engineering (Bottoms Up) and Actual Costs.

Few estimates employ the same estimating technique for every cost element. The techniques used to develop the estimates for various cost elements should take into account the stage of the acquisition cycle that the program is in when the estimate is made (e.g., Concept & Technology Development (Concept Exploration for grandfathered programs[1])). OSD prefers that heavy reliance be placed on parametric, as well as analogy and engineering methods, for Milestone B and C reviews (Milestones I and II for grandfathered programs), while extrapolation from cost actuals should be used to the maximum extent possible in preparing estimates for the Full Rate Production Review (Milestone III for grandfathered programs) and any subsequent actions. A comparison of several estimates using different cost estimating methods is encouraged.

ANALOGY METHOD

The analogy method compares a new system with one or more existing systems for which there are accurate cost and technical data. The estimator/analyst makes a subjective evaluation of the differences between the new system of interest and historic systems. An example would be estimating the cost of a new car (2002) based on what you paid for your last car (1995) of the same type. Normally, engineers are asked to make the technical evaluation of the differences

[1] This teaching note refers to the defense acquisition process defined in the 2002 versions of DoD Directive 5000.1, DoD Instruction 5000.2, and DoD 5000.2-R. "Grandfathered" programs are those programs that continue to operate under the process described in the 1996 versions of DoDD 5000.1 and DoD 5000.2-R. Not incorporated are expected changes to DoD Directive 5000.1 and DoD Instruction 5000.2 currently in draft form. It is expected that DoD 5000.2-R will be cancelled and probably rewritten as a guidance manual.

between the systems. Based on the engineers' evaluation, the cost estimator/analyst must assess the cost impact of the technical difference(s). For example, suppose the engineer determines that the only significant difference is that the new car is 30 percent more complex than our old car, due to added electronic systems. We might be tempted to simply increase our 1995 car's cost by 30% to account for this increase in complexity. However, since the cost of electronic systems dropped 5 percent per year between 1995 and 2002, the cost estimator/analyst might decide to weight this complexity increase by only 65 percent (5 percent cost reduction per year for 7 years equates to a 35 percent cost drop or 65 percent weighting). Therefore, a $12,000 1995 car weighted to reflect the added complexity and cost factors would yield a cost of (.30) (.65) (12,000) + 12,000 = $14,340 for the 2002 car in 1995 constant dollars. Of course, this does not tell us how much the car will cost today until we factor in inflation. Assuming that inflation averaged 4% a year between 1995 and 2002, we need to multiply the 1995 constant dollar amount by 126.5% to arrive at an estimate in current 2002 dollars ($18,140).

Uncertainty in a cost estimate using analogy is due to subjective evaluations made by the technical staff and cost estimators/analysts in their determination of the cost impacts of the differences between the old and new systems. In many cases, objective technical comparisons can be made. For example, a new system may have 100 square inches of circuit board with 10 discrete components and 500,000 operations compared to the old system of 500 square inches, 250 discrete components, and 100,000 operations. The problem then is to develop a cost relationship based on the technical differences.

One does not have to compare the new system to just one other analogous system. It may be desirable to compare some subsystems of the new system to subsystems of old system A, and others to subsystems of old system B. For example, to estimate the cost of a new radar, you may find an analog for the transmitter which is different from the analog(s) for the exciter, antenna, processors, etc. The key is in making pair-wise comparisons for each system or subsystem being evaluated. The total system cost estimate thus may be the sum of many single analogy-based cost estimates.

The analogy method is very appropriate early in the program life cycle when the system is not yet fully defined. This assumes there are analogous systems available for comparative evaluation. (See **Figure 1**.)

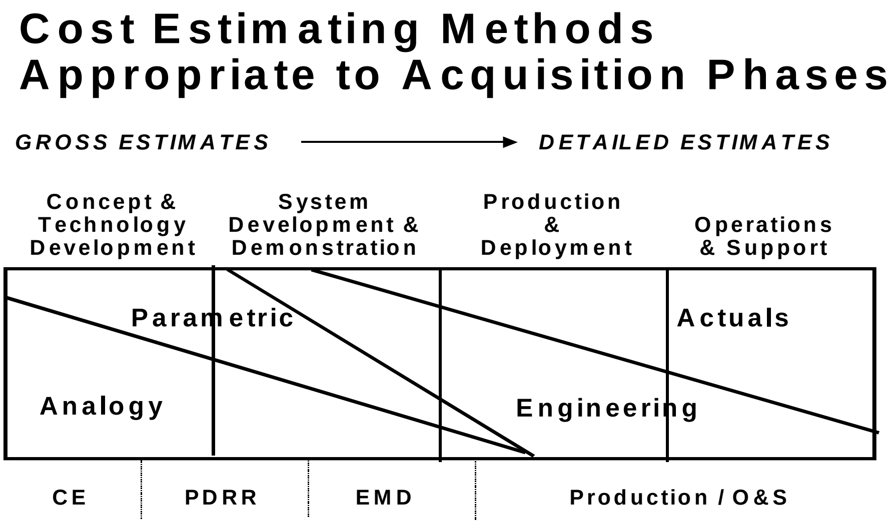

Figure 1

PARAMETRIC METHOD

The parametric, or statistical, method uses regression analysis of a database of similar systems to develop ***cost estimating relationships (CERs)*** which estimate cost based on one or more system performance or design characteristics (e.g., speed, weight, thrust). Parametric estimating is used widely in government and industry because it can yield a multitude of quantifiable measures of merit and quality, i.e., probability of success, levels of risk, etc. Additionally, CERs developed using the parametric method can easily be used to evaluate the cost effects of changes in design, performance, and program characteristics. Note that the parametric method, which makes *statistical inferences* about the relationship between cost and one or more system parameters is very different from drawing analogies to multiple systems.

A critical consideration in parametric cost estimating is the similarity of the systems in the underlying database, both to each other and to the system which is being estimated. A good parametric database must be timely and accurate, containing the latest available data reflecting technology similar to that of the system of interest (design, manufacturing/assembly, material). For example, attempting to estimate the cost of a current day computer (electronic memory chips) using a database of older computers (magnetic core memory) would yield an estimate much higher than the actual cost of the current system because the memory chips are much cheaper to produce and install than the old core memory. In addition, changes in manufacturing technology or processes have occurred, such as the use of automatic insertion equipment instead of hand insertion of components onto printed circuit boards (PCBs). This has led to major reductions in the labor content associated with the assembly of PCBs.

Additionally, the database must be homogenous. A data element entry for one system must be consistent with the same data element entry for every other system included in the database. For example, in a rocket motor database where there is an element called the "motor weight", each weight entry should be based on the same assumptions for each system. Assume that each motor is defined to include the rocket grain, motor case, and nozzle. If some systems report a motor weight which does not include one or more of these components (or includes additional components), then the database is not homogenous and CERs developed from the database are questionable, to say the least. Too often a database is built over time, with inputs from various sources, without any one individual responsible for insuring the homogeneity of the data.

The validity of a CER is usually judged by its regression statistics, which measure the accuracy of the fit of the CER to the sample data points used in developing the CER. The most commonly used regression statistic is the coefficient of determination (R^2). A CER that perfectly predicted each sample point in the database would have an R^2 of 1.0. For CERs, an R^2 value of .9 or better is considered desirable, although in practice, CERs with R^2 values of .8 or better may be accepted for use in a cost estimate.

A CER which meets the criteria of data homogeneity and good regression statistics may still be unsuitable for use in a particular system's cost estimate if the value of the new system's parameters fall outside the range of the parameter values for the existing systems in the database. For example, a CER developed from data on aircraft that travel at less than the speed of sound may not predict costs well for a system which is to travel at supersonic speeds.

The parametric method is appropriate early in the program life cycle (Figure 1) when a detailed design specification is not available, but a database of like systems and a performance specification are available. The parametric method is also useful as a check against an estimate made using another method.

ENGINEERING METHOD

The engineering or "bottoms up" method of cost analysis is the most detailed of all the techniques and the most costly to implement. With this technique we start at the lowest level of definable work within the Work Breakdown Structure (WBS) (e.g., milling a flange). The direct labor hours required to complete the work are estimated from engineering drawings and specifications, usually by an industrial engineer (IE) using company or general industry "standards". The engineers also estimate raw materials and purchase parts requirements. The remaining elements of cost, such as tooling, quality control, other direct costs, and various overhead charges including systems engineering and project management, are factored from the estimated direct labor and/or material content of the work. The actual portion of the cost estimated directly is thus a fraction of the overall cost of the system.

The IE may use a variety of techniques in estimating the direct labor and material cost of each discrete work element. For example, the IE may use an analogy to estimate one work element; a parametric CER based on an industry database of like work elements to estimate a second work element; and a set of work standards based on work activities (e.g., milling .002 inches from a 6 inch diameter rod 3 inches long) to estimate a third work element.

Uncertainty in this type of cost estimate is due to the use of multiplicative factors on the relatively small direct labor/material base that was estimated. This can result in significant error in the total system cost estimate. The uncertainty, however, can be assessed and managed.

Another potential problem is that since the cost estimate is the summation of many estimates, it may be hard to maintain the documentation to support the estimate.

Since, in most cases, the engineering estimate is based on standards, either company-specific or industry-wide, the contractor's cost estimate should be "attainable". By definition, standards are attainable values for specific work under given conditions. The engineering estimate is thus a tool for the manufacturer to control the work on the floor (process control). The technique has its greatest value once the design has stabilized and the system is in production.

As DoD weapon systems development programs tend to be on the leading edge of technology, much effort is spent getting the system to work, which translates into redesign and modifications. This design metamorphosis should be reflected in the engineering estimate. However, the IE may, due to the unknown aspects of the program, underestimate the number of design iterations and therefore underestimate the cost of the work element(s).

The engineering cost estimate is most often used during the production and deployment phase (Figure 1). This technique encourages the contractor to do his homework early on and define all the work down to the lowest level of the WBS. It is also a great process control technique at the production facility. The technique, generally accomplished by hardware manufacturers, is the most costly in time and people.

ACTUAL COSTS

Actual cost experience on prototype units, early engineering development hardware and early production hardware for the program under consideration should be used to the maximum extent possible. If development or production units (or components) have been produced, the actual cost information should be provided as part of the documentation. Estimates for Full Rate Production decision reviews are to be based at least in part on actual production cost data for the systems under review.

The technique of using actual cost data (or extrapolating future estimated cost from actual costs) is based on data from earlier/previous units of the same system. This is probably the most accurate cost estimating method when the data is available (Figure 1). The OSD Cost Analysis Improvement Group (CAIG) prefers this method since it uses actual or near actual data for the system of interest. The uncertainty associated with this method is based, as with the analogy method, on the technical assessment of the differences between an earlier version of the system, such as a prototype, and the current model under consideration. Obviously, the more the two versions are alike, and the further along the system is in the acquisition process, the more easily an accurate estimate can be made.

SUMMARY

Of the four cost estimating methods presented, the use of actual costs is the most supportable, but difficult to accomplish early in the acquisition program. The analogy method is most often used early in the program, when little is known about the specific system to be developed. The parametric technique is useful throughout the program, provided there is a database of sufficient size, quality, and homogeneity to develop valid cost estimating relationships. The engineering estimate is used later in program development and production, when the scope of work is well defined and an exhaustive Work Breakdown Structure can be developed.

In all cases, no matter what the estimating technique, the program manager must ensure the cost estimate completely defines the program and is technically sound and reasonable. The cost estimate must be defensible with well-reasoned analysis. A program manager who is totally familiar with the program's cost estimate, including the rationale for the method(s) used to develop that estimate, generally is in control of the program.

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